DarkSide and MAX

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Dark Matter

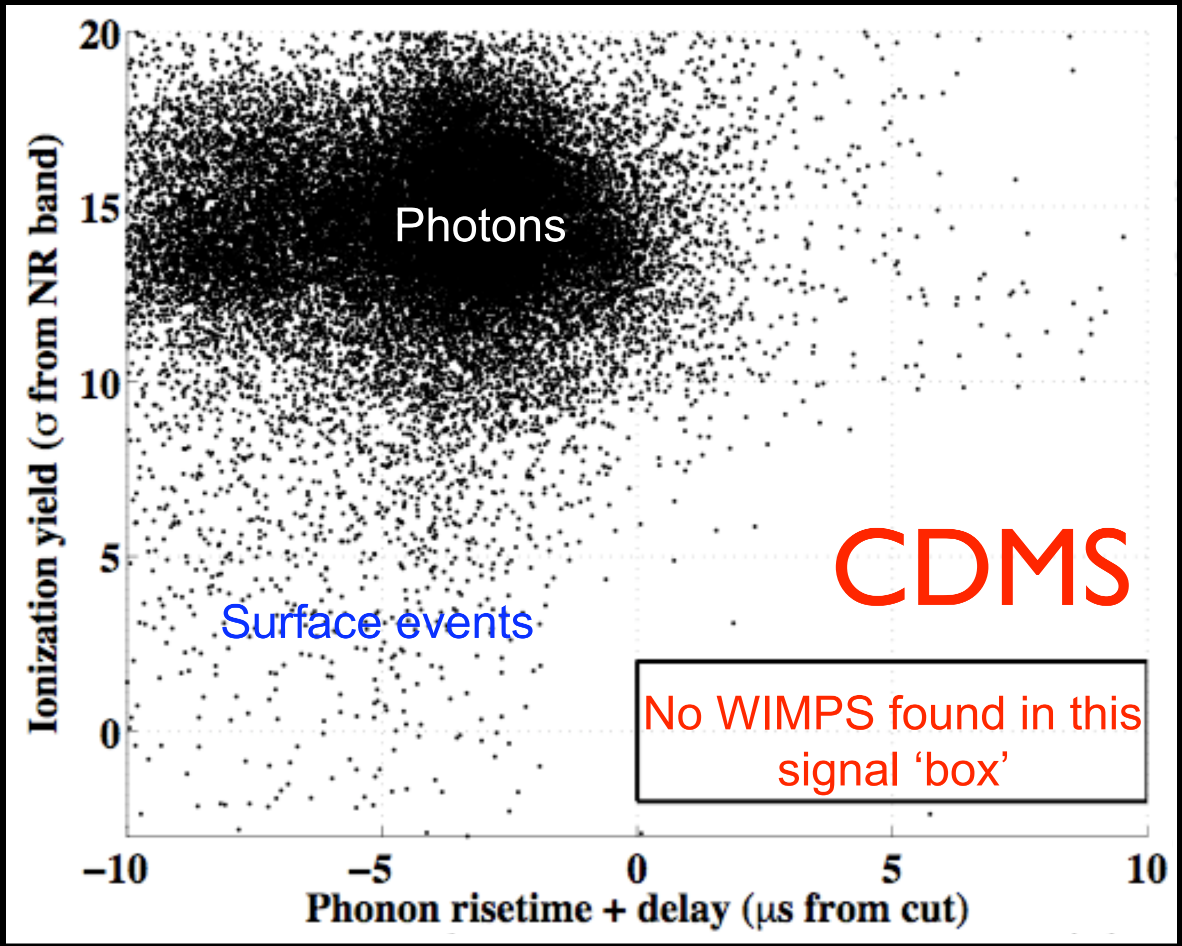
- Strong and convincing evidence for new physics beyond Standard Model
  - Unambiguous evidence
  - Possibly connected with electroweak symmetry breaking, SUSY, and structure formation
- Bright prospects for experimental observation
  - Astroparticle physics: direct and indirect searches
  - Particle physics: CMS and ATLAS at LHC
  - Cosmology: halo profiles, CMB, BBN

Program Goal

- Bring together techniques that offer the best characterization and rejection of background in noble liquid detectors
- The goal is: zero background (à la CDMS) with very large exposure - many tons·years
- Choice of LAr dual-phase TPC (WARP) offers many handles on background
  - P. Benetti et al., Nucl. Instr. Meth. A **327**, 203 (1993); M.G. Boulay and A. Hime, Astropart. Phys. **25**, 179 (2006); P. Benetti et al. (WARP Collaboration), Astopar. Phys. **28**, 495 (2008).
- DarkSide program introduces 3 innovative technologies crucial for achievement of zero background in very large detectors

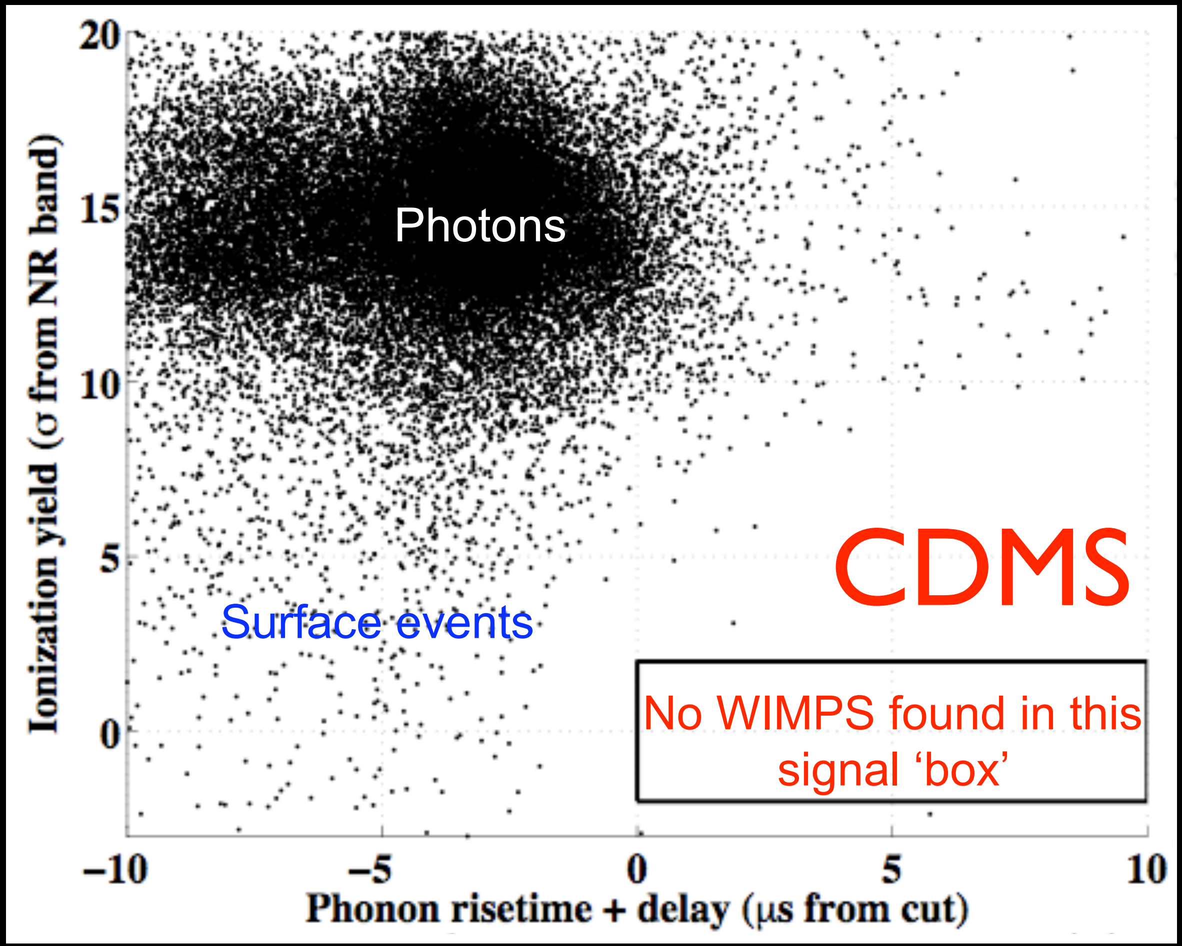
Game Changing Technologies

1. Depleted Argon from underground sources
2. 3" QUPID photosensors
   - no background detected in best Ge
   - new Bialkali-LT photocathode form Hamamatsu for high QE at liquid argon temperature
3. High efficiency borated liquid scintillator neutron veto (>99%)



Ionization yield (σ from NR band)
20
15
10
5
0
Photons
Surface events
CDMS
No WIMPS found in this signal 'box'
−10
−5
0
5
10
Phonon risetime + delay (μs from cut)

Two is Better than One!



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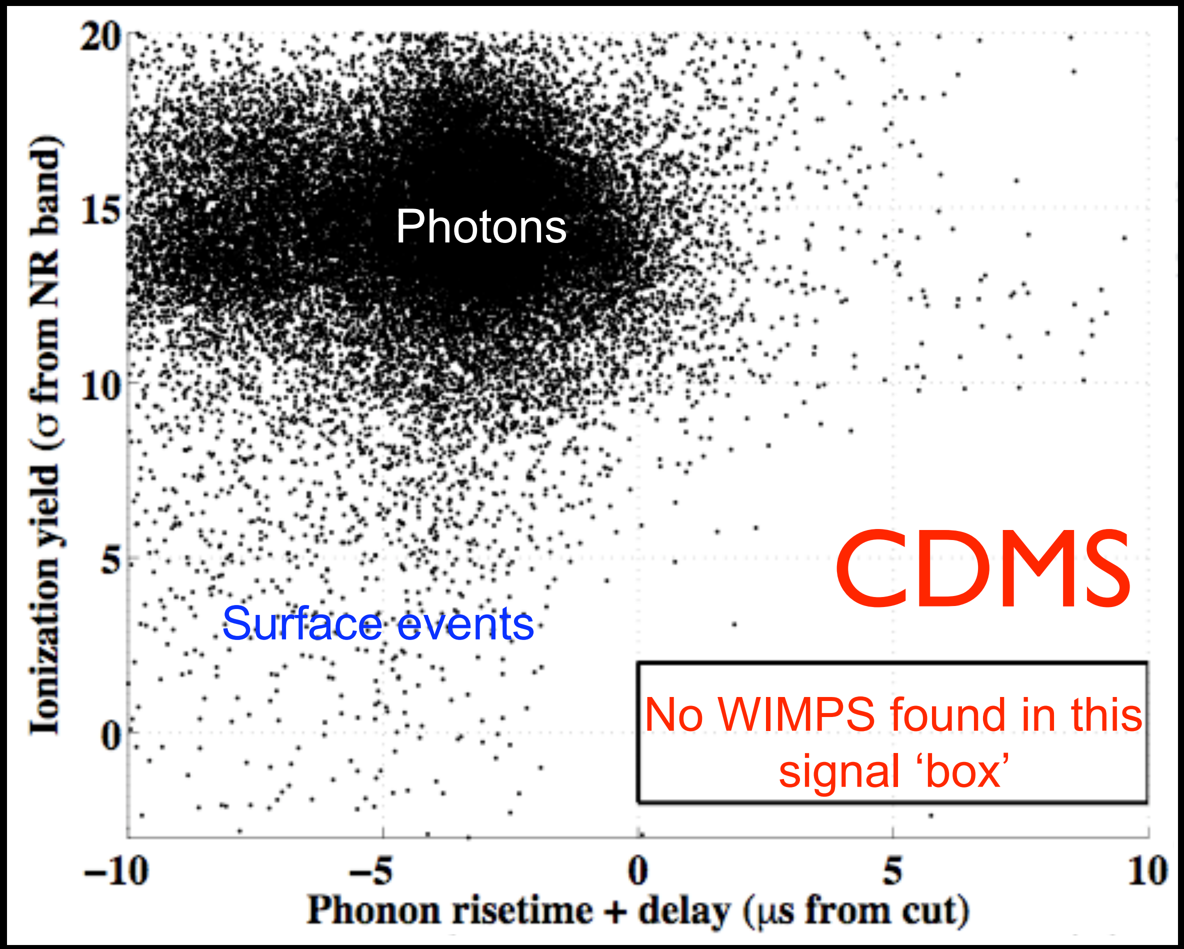
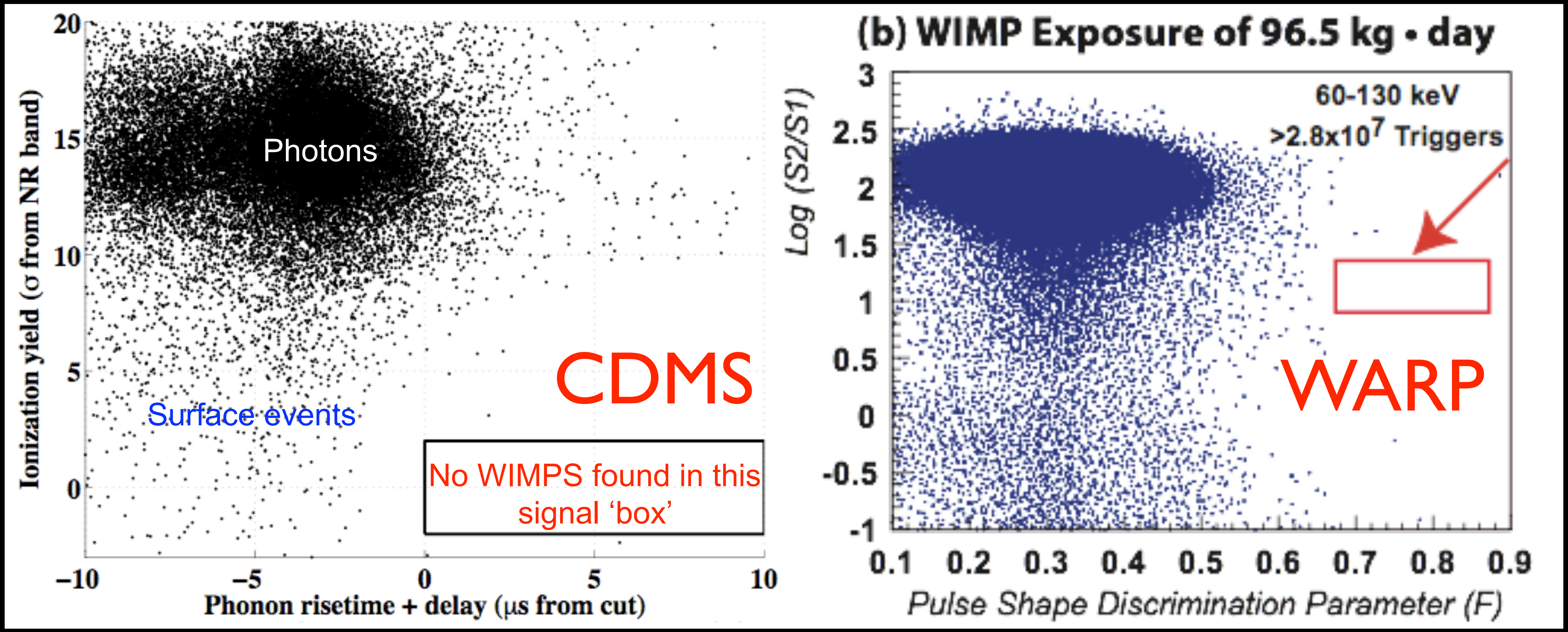


Required Identification of few events in ~Tons per Yr at few tens of keV with zero background!

Presence of dual, semi-independent discrimination crucial

Two is Better than One!



Required Identification of few events in ~Tons per Yr at few tens of keV with zero background!

Presence of dual, semi-independent discrimination crucial

DarkSide and MAX

DarkSide Collaboration

- DarkSide-50 (10^{-45} cm^2)

XENON Collaboration

- XENON-100 (10^{-45} cm^2) and XENON-100+ (10^{-46} cm^2)

DarkSide + XENON = MAX Collaboration

- 5t Depleted Argon and 2.5t Xe TPCs (10^{-47} cm^2)
- S4 Funded Project
- Possible change in baseline (25t DAr, 10t Xe) if DUSEL delay to 2016-2017 confirmed

Dark Matter Project Specifics

- To advance the CDMS technology, **PASAG recommends a technical review of SuperCDMS in FY2010 to evaluate the performance of the new detectors currently in operation at Soudan. Funding for the 100-kg SuperCDMS-SNOLAB experiment should begin as soon as the detectors meet the design requirements.**

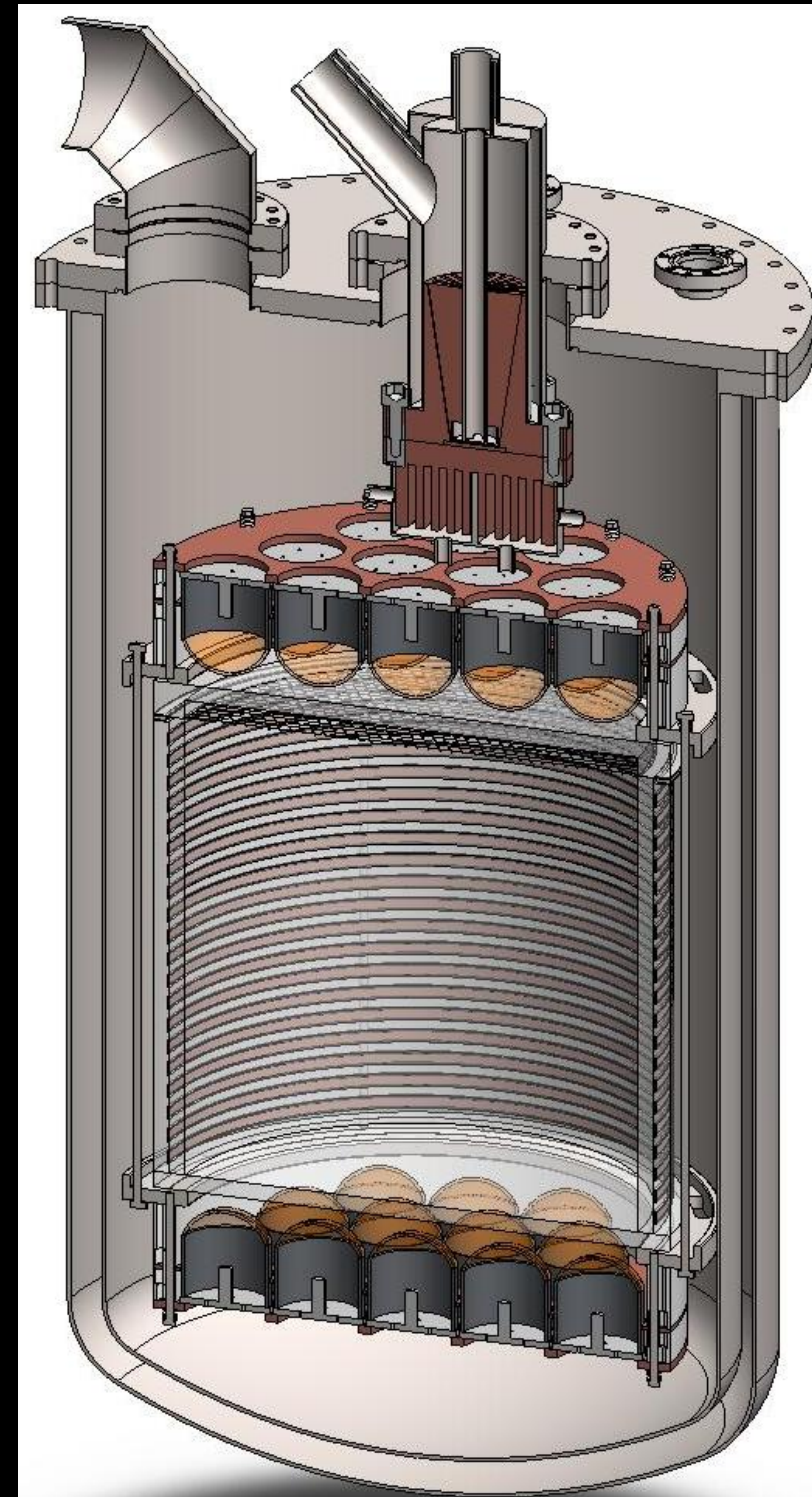
- **A future xenon program that avoids duplicate efforts and meets the technical requirements for low background should be supported in any of the funding scenarios.**

- **The liquid argon technique may be especially promising with the use of depleted argon and should also be explored in any of the funding scenarios.**

- **Specific Findings and recommendations for Axion Detection:**
  - ADMX completed phase-I construction and is operating well. It is estimated to take a total of 1-2 years to cover 10^{-6}-10^{-5} eV down to the first of two model benchmark sensitivities (KSVZ). Phase II of the experiment will cover the same range down to the lower model (DFSZ). This phase requires a

DarkSide-50

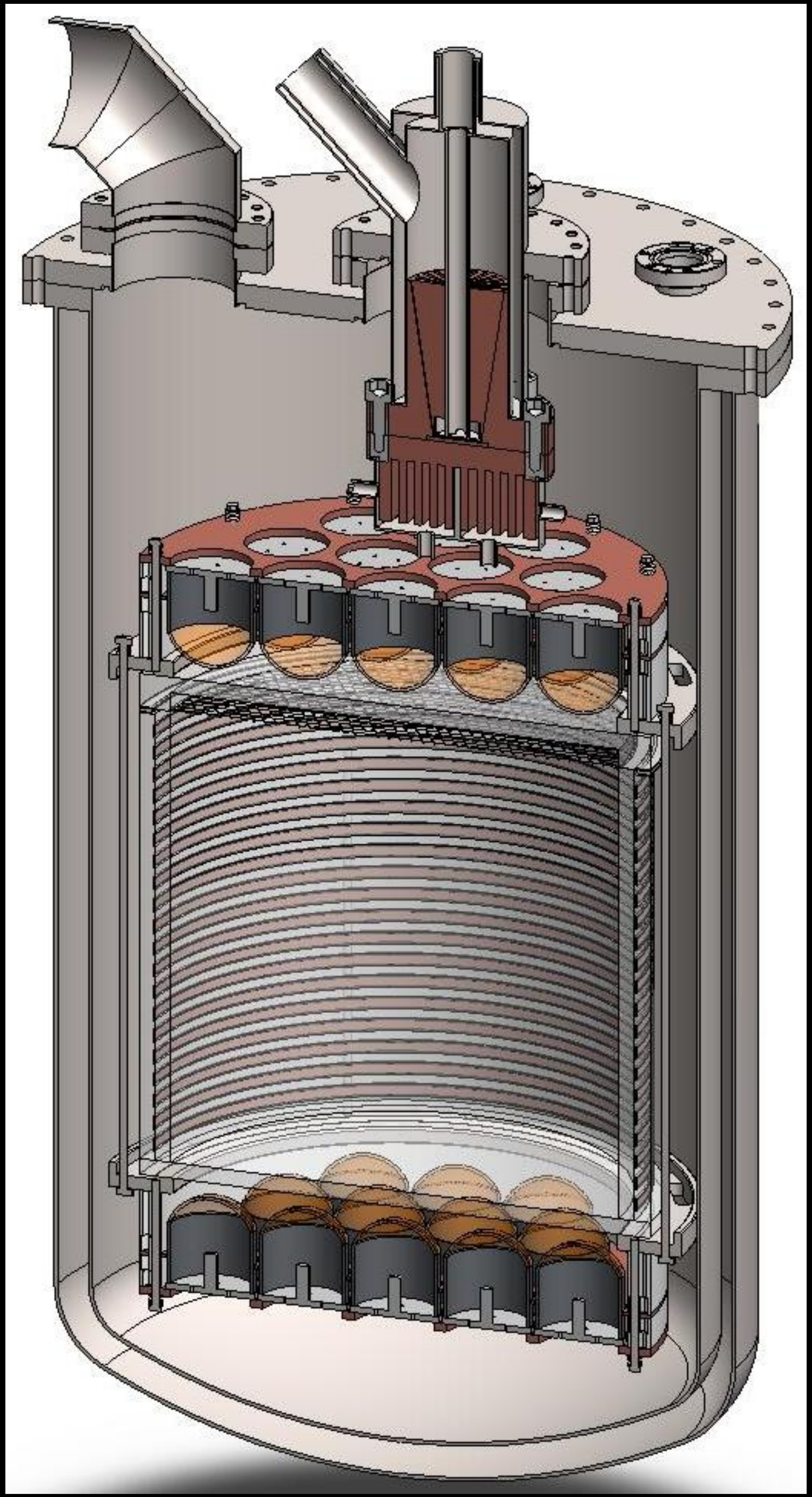
dual-phase TPC
50 kg active mass
5 ph.el/keV$_{ee}$
23 keV$_r$ threshold
background-free for 3 yrs
sensitivity 10^{-45} cm^2

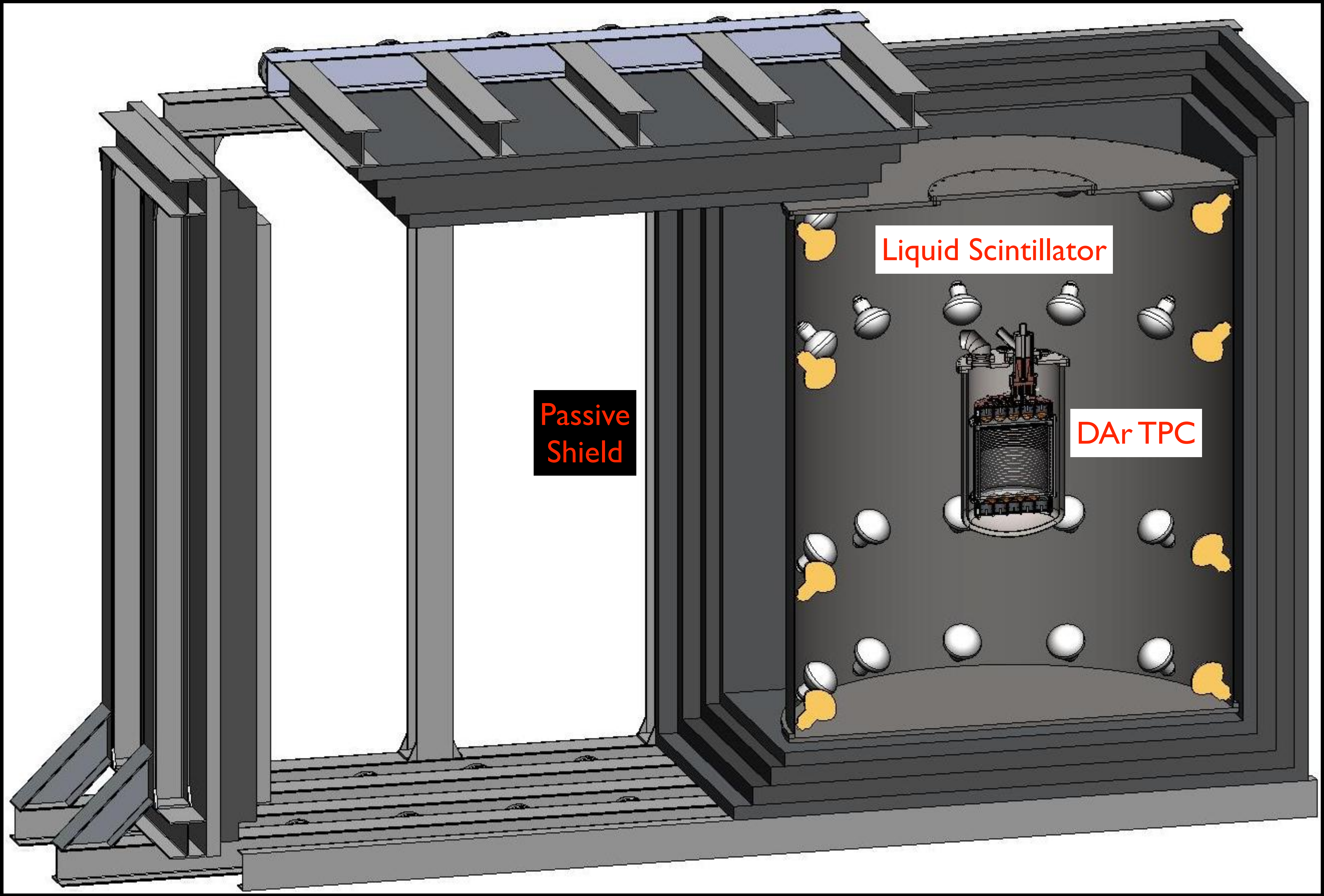


DarkSide-50

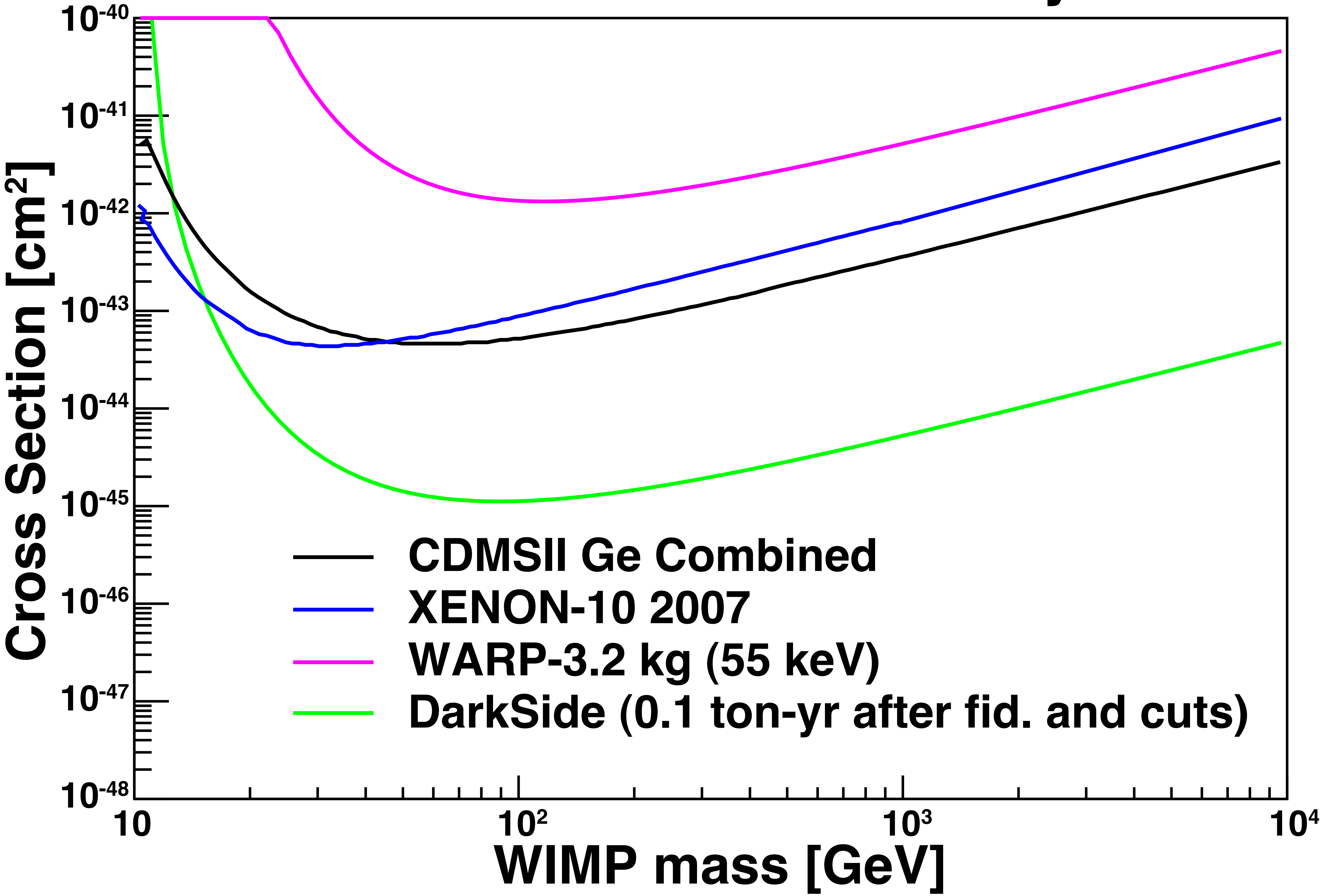
First test for three technological advances crucial to achieve zero background:

1) depleted argon
2) QUPIDs at LAr temp
3) active liquid scintillator neutron veto




Liquid Scintillator
Passive Shield
DAr TPC

Cross Section Sensitivity



DarkSide

UMass Amherst
Arizona State University
Augustana College
Black Hills State University
Fermilab
University of Houston
University of Notre Dame
Princeton University
Temple University
UCLA

Augustana College, USA Prof. Drew Alton

Black Hills State University, USA Prof. Dan Durben, Prof. Kara Keeter, Prof. Michael Zehfus

Fermi National Accelerator Laboratory, USA Dr. Steve Brice, Dr. Aaron Chou, Dr. Jeter Hall, Dr. Hans Jostlein, Dr. Stephen Pordes, Dr. Andrew Sonnenschein

Princeton University, USA Jason Brodsky, Prof. Frank Calaprice, Huajie Cao, Alvaro Chavarria, Ernst de Haas, Prof. Cristiano Galbiati, Eng. Augusto Goretti, Eng. Andrea Ianni, Tristen Hohman, Ben Loer, Pablo Mosteiro, Prof. Peter Meyers, Eng. David Montanari, Allan Nelson, Eng. Robert Parsells, Richard Saldanha, Eng. William Sands, Dr. Alex Wright, Jingke Xu

Temple University, USA Prof. Jeff Martoff, Prof. Susan Jansen-Varnum, Christy Martin, John Tatarowicz

University of California at Los Angeles, USA Prof. Katsushi Arisaka, Prof. David Cline, Chi Wai Lam, Kevin Lung, Prof. Peter F. Smith, Artin Teymourian, Dr. Hanguo Wang

University of Houston, USA Prof. Ed Hungerford and Prof. Lawrence Pinsky

University of Massachusetts at Amherst, USA Prof. Laura Cadonati and Prof. Andrea Pocar

University of Notre Dame, USA Prof. Philippe Collon, Daniel Robertson, Christopher Schmitt

University of Virginia, USA Prof. Kevin Lehmann

Discrimination in Argon

- Pulse shape discrimination of primary scintillation (S1) based on the large difference in decay times between singlet ($\approx$ 7 ns) and triplet (1.6 μs) components of the UV scintillation light

  Minimum ionizing: triplet/singlet ~ 3/1

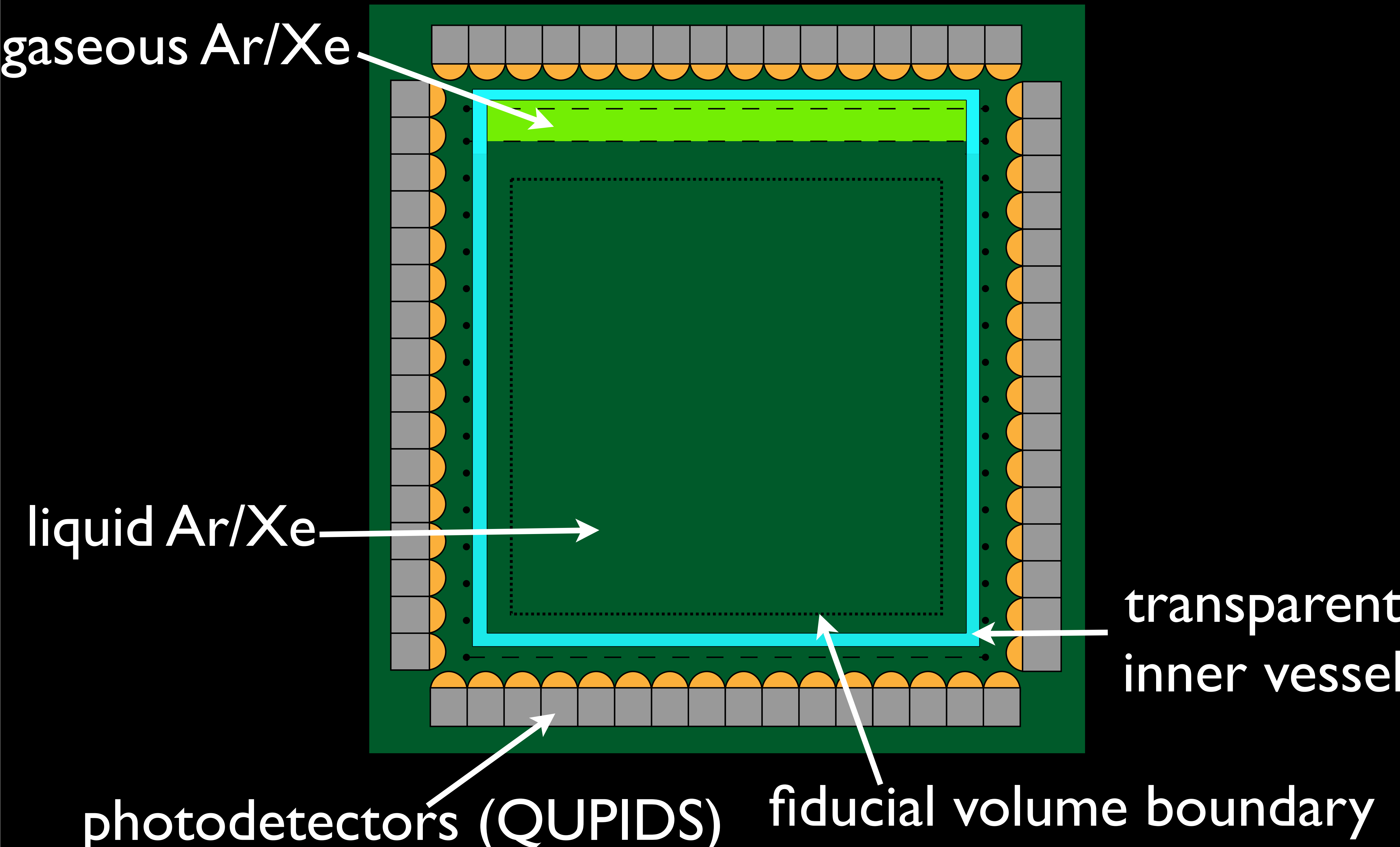
  Nuclear recoils: triplet/singlet ~ 1/3

  Theoretical Identification Power exceeds 10^8 for > 60 photoelectrons (Boulay & Hime 2004)

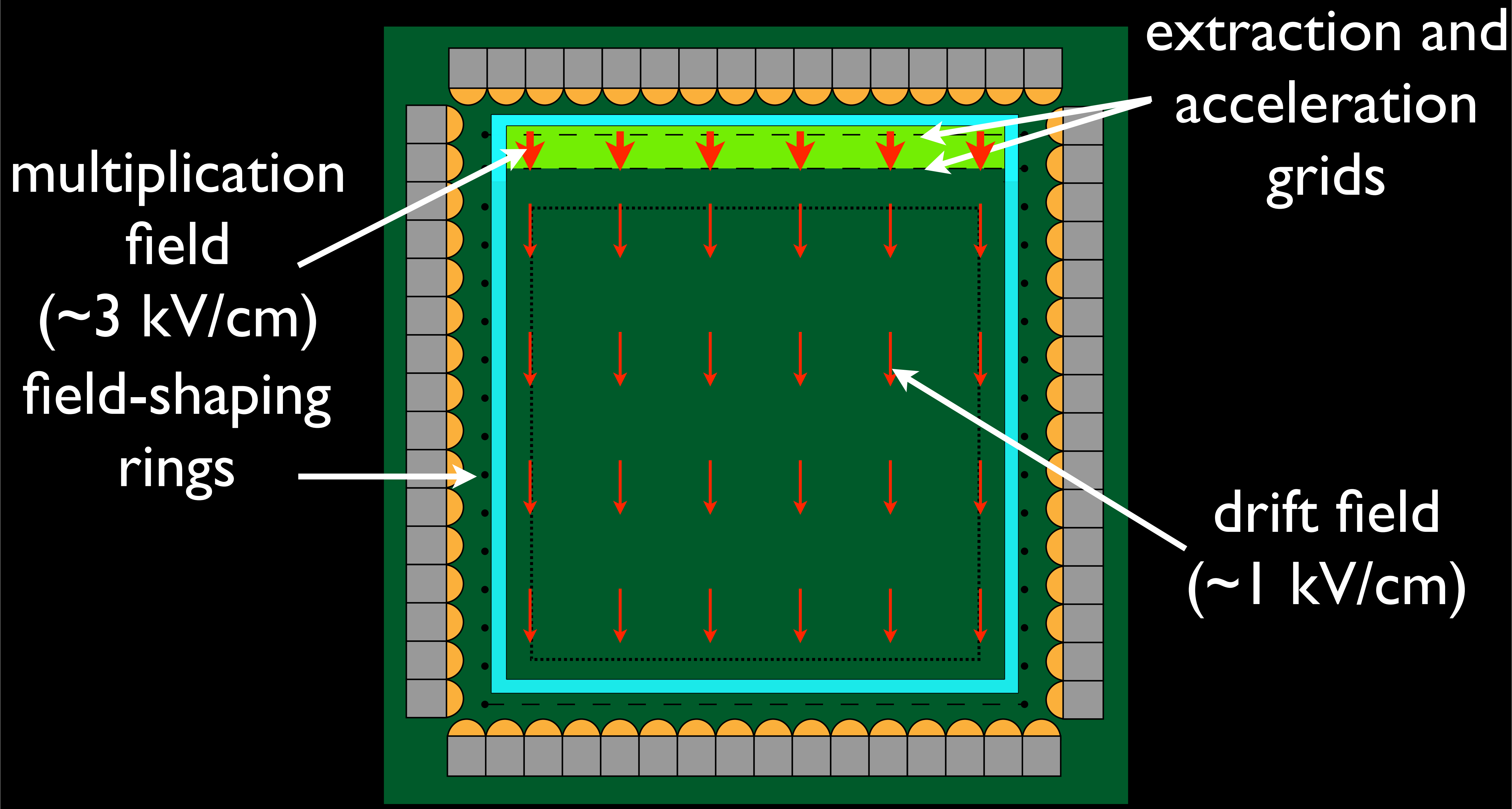
- Difference in ratio of the prompt scintillation (S1) to the drift time-delayed ionization (S2) strongly dependent upon recombination of ionizing tracks, which in turn depends on ionization density
  - Rejection ~ 10^2-10^3

- Precise determination of events location in 3D
  - 1-5 mm x-y, 1 mm z
  - Additional rejection for neutron and γ background

TPC in Action

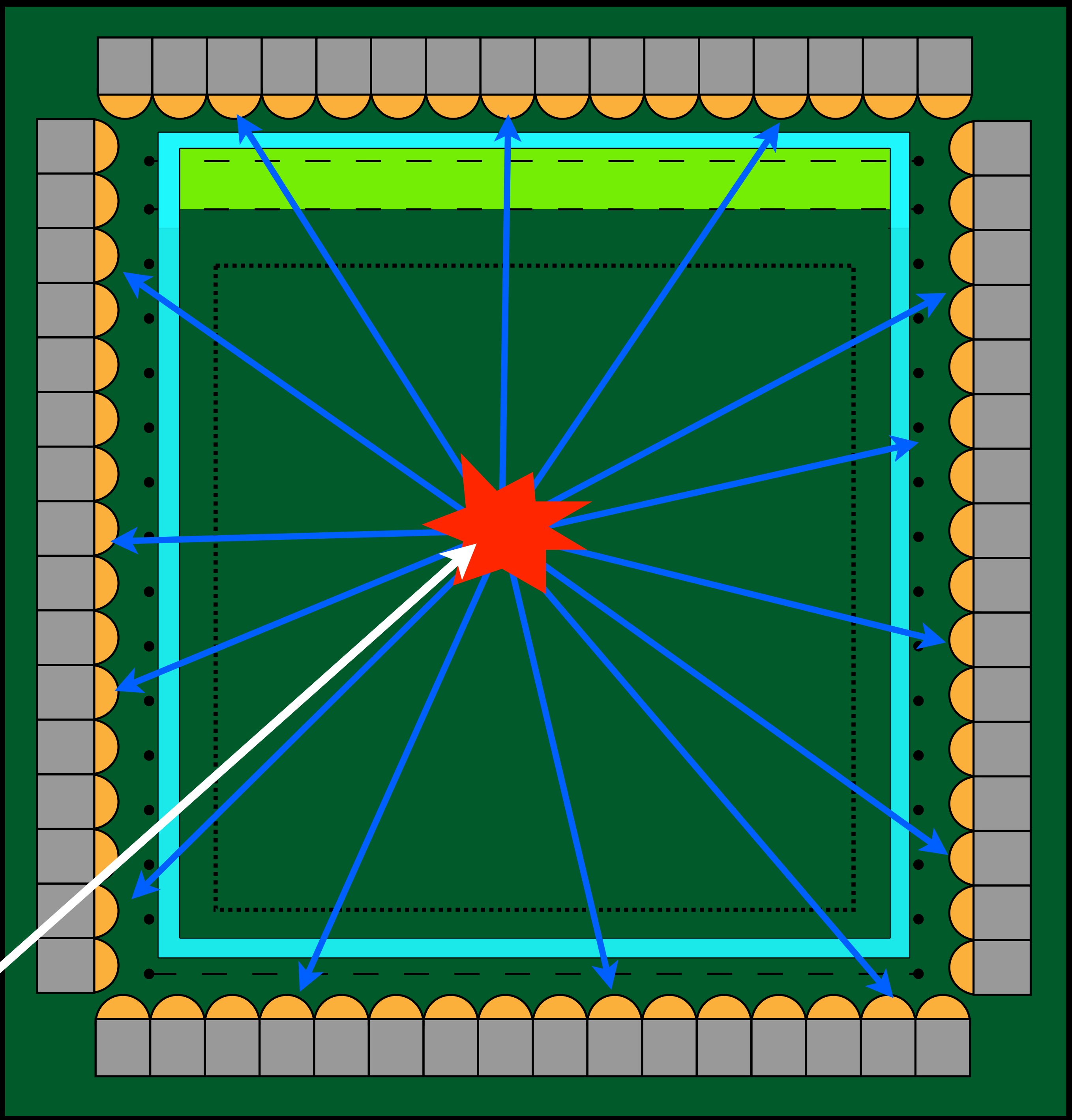


TPC in Action



TPC in Action

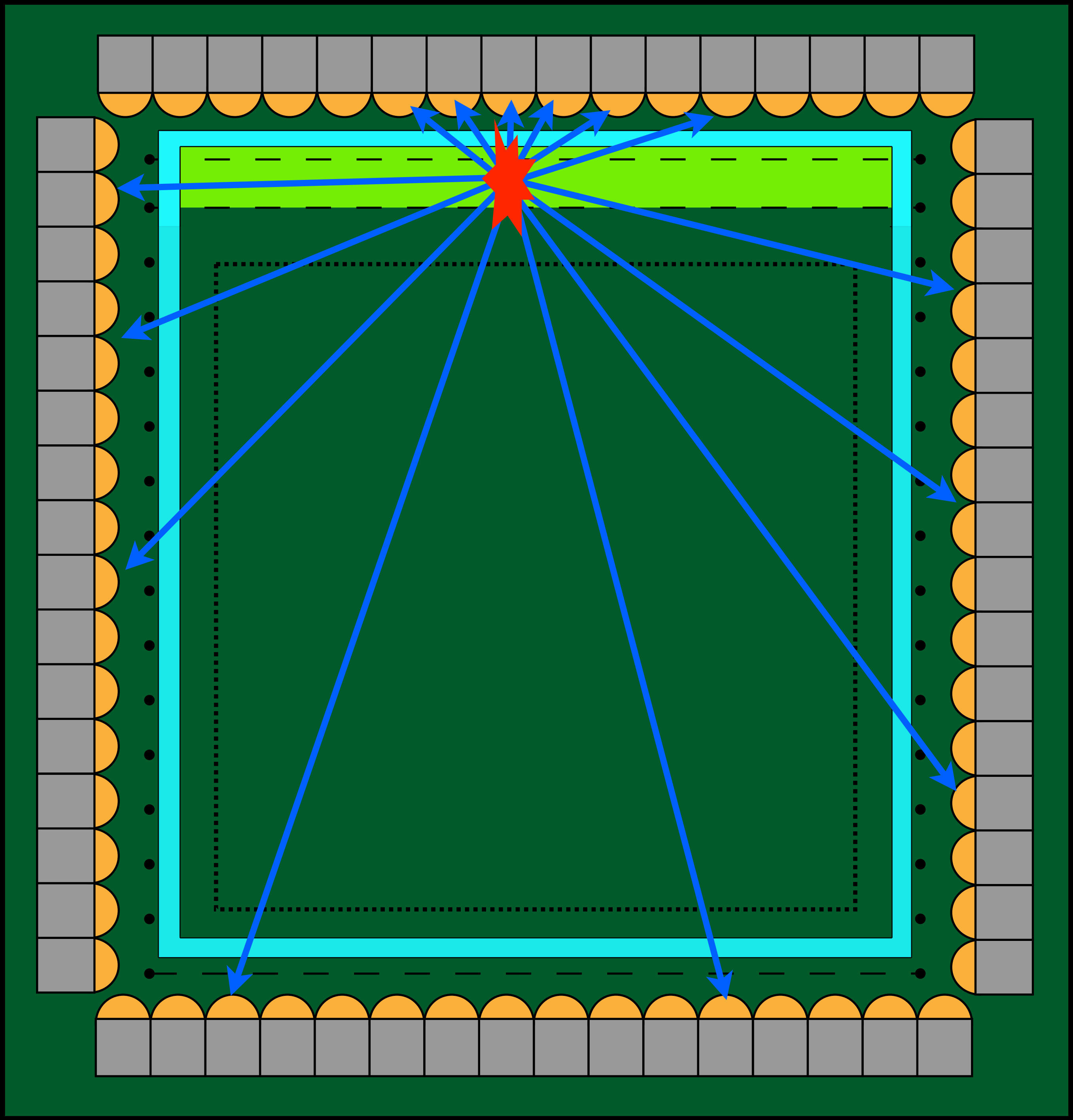
primary scintillation photons
emitted and detected



WIMP Scatter
deposits
energy in FV

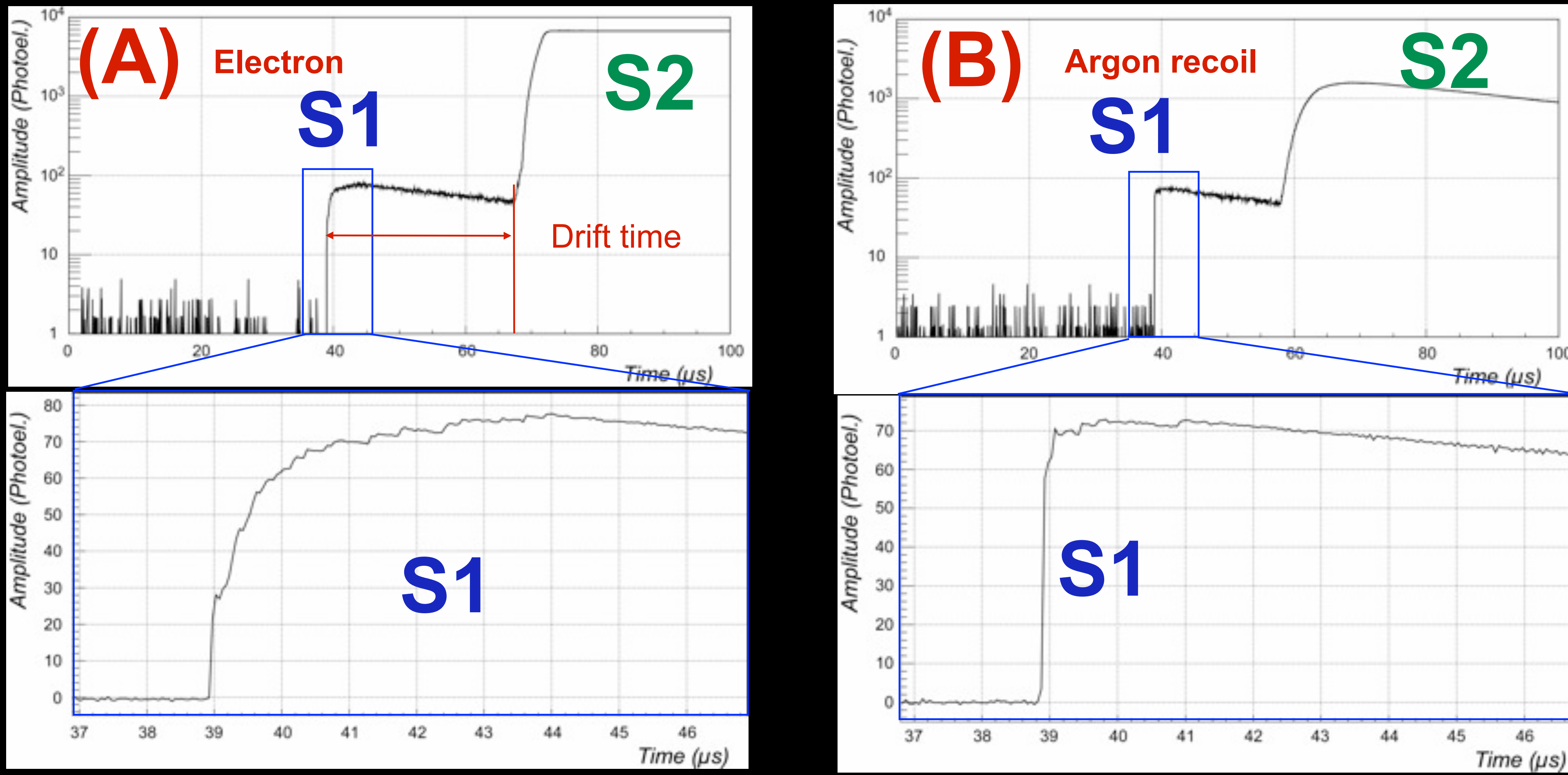
TPC in Action

secondary photons emitted
by multiplication in gas region



ionized
electrons
drifted to
gas region

First Two Discrimination Methods



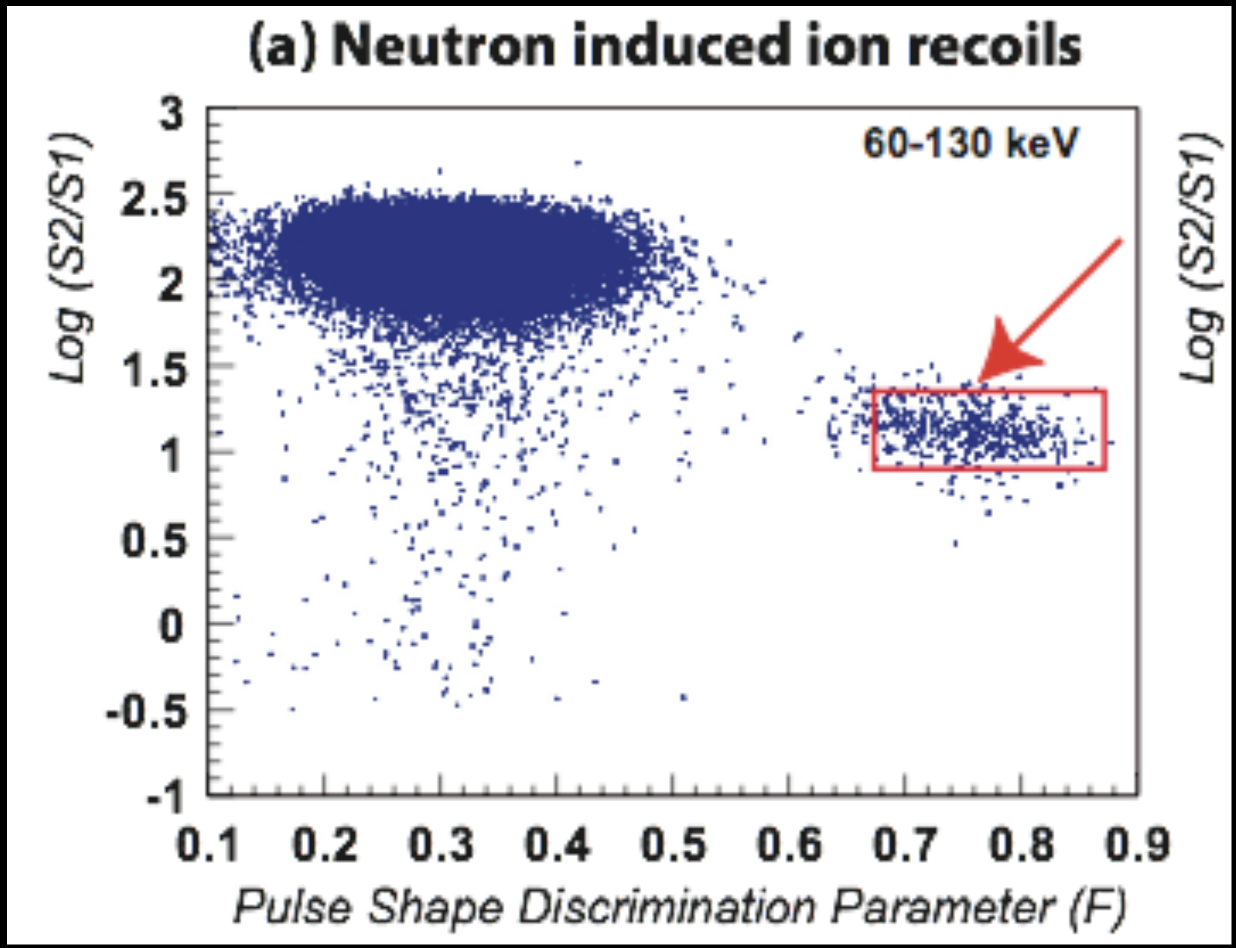
Events are characterized by:

- the ratio S2/S1 between the primary (S1) and secondary (S2)
- the rising time of the S1 signal

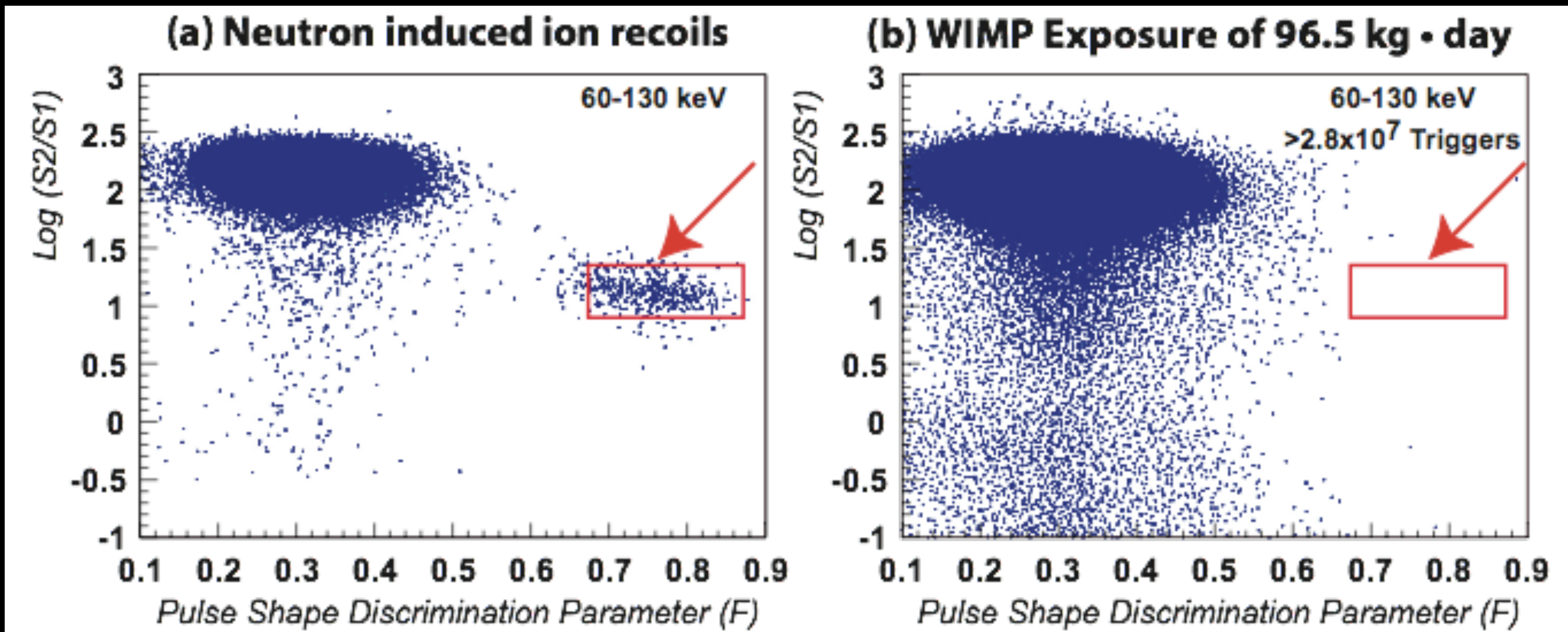
Minimum ionizing particles: high S2/S1 ratio (~100) and by slow S1 signal

Ar recoils: low (≤10) S2/S1 ratio and fast S1 signal

First Dark Matter Results



First Dark Matter Results



Events in the recoils window during the WIMP search run: zero

P. Benetti et al. (WARP Collaboration), Astropart. Phys. **28**, 495 (2008)

2-Phase vs 1-Phase

- 2-Phase argon detector more complex and complete than 1-Phase
  - Additional complexity similar to that of 2-Phase xenon TPCs (XENON, ZEPLIN, LUX) and 2-Phase argon TPC (WARP)
- 2-Phase technology well tested and understood
- Three out of three DM results with noble liquid detectors come from 2-Phase ... no results from 1-Phase yet

2-Phase vs 1-Phase

- At cost of modest increase in complexity, 2-Phase adds two more discrimination criteria
  - Fundamental to achieve zero background
  - Sharp position resolution crucial for surface background
- Use all background rejection tools available in nature
- 2-Phase detector compatible with 4π optical readout and high light yield

Why is depleted argon from underground crucial?

- Radioactive ^{39}Ar produced by cosmic rays in atmosphere
  - beta decays, Q = 565 keV, $t_{1/2}$ = 269 years
- In atmospheric argon:
  - $^{39}Ar/Ar$ ratio 8×10^{-16}
  - specific activity 1 Bq/kq
- Limits size (and sensitivity) of argon detectors to 500-1000 kg due to ^{39}Ar events pile-up

Why is depleted argon from underground crucial?

- ^{39}Ar-depleted argon available via centrifugation or thermal diffusion, but expensive at the ton scale!

- Motivated by suggestion from Bernard and success in Borexino
  - Low background from ^{14}C crucial for observation of low energy neutrinos with organic liquid scintillators.
  - Hydrocarbons in deep underground reservoirs results in low cosmogenic ^{14}C

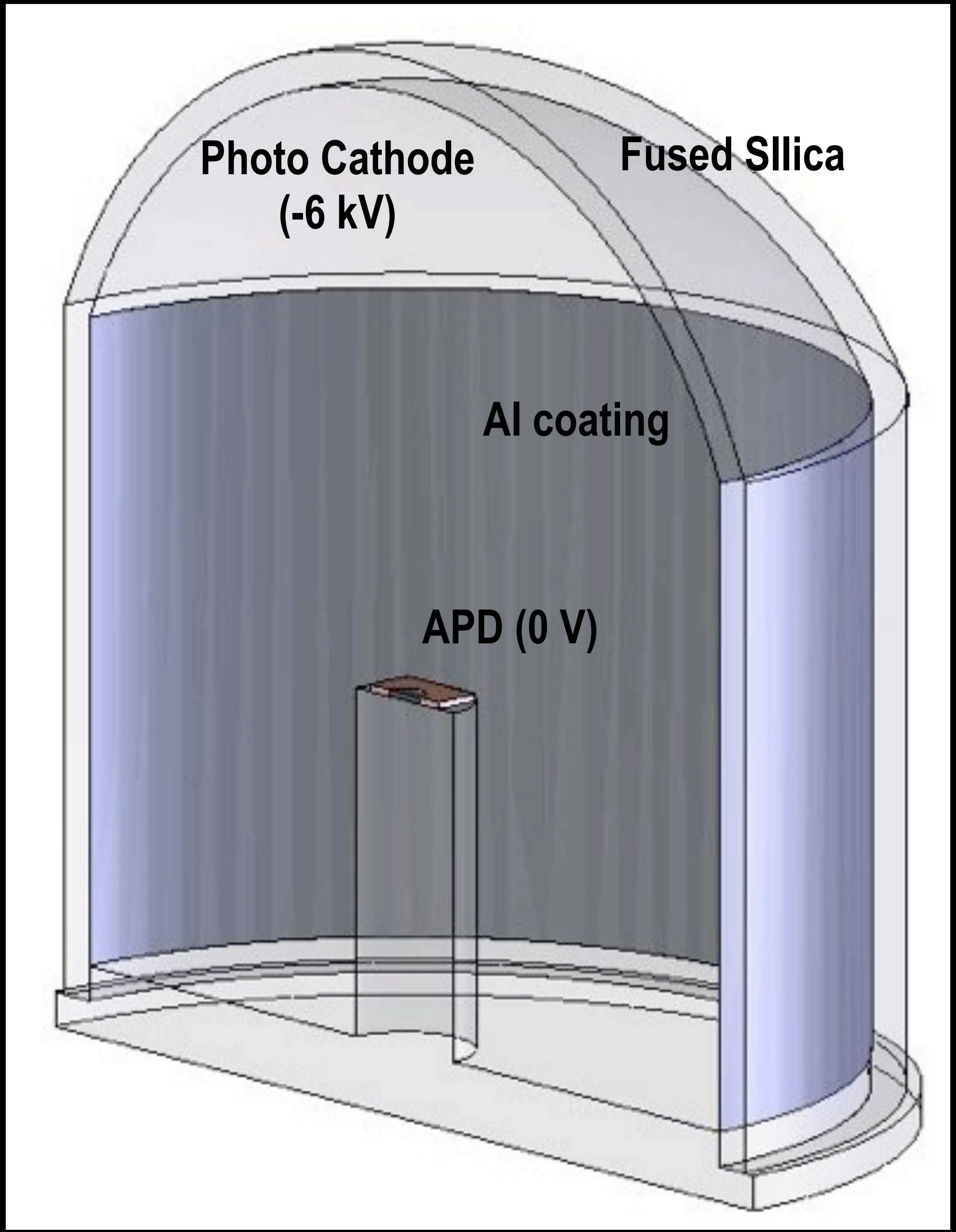
- ^{39}Ar production by cosmic rays strongly suppressed underground

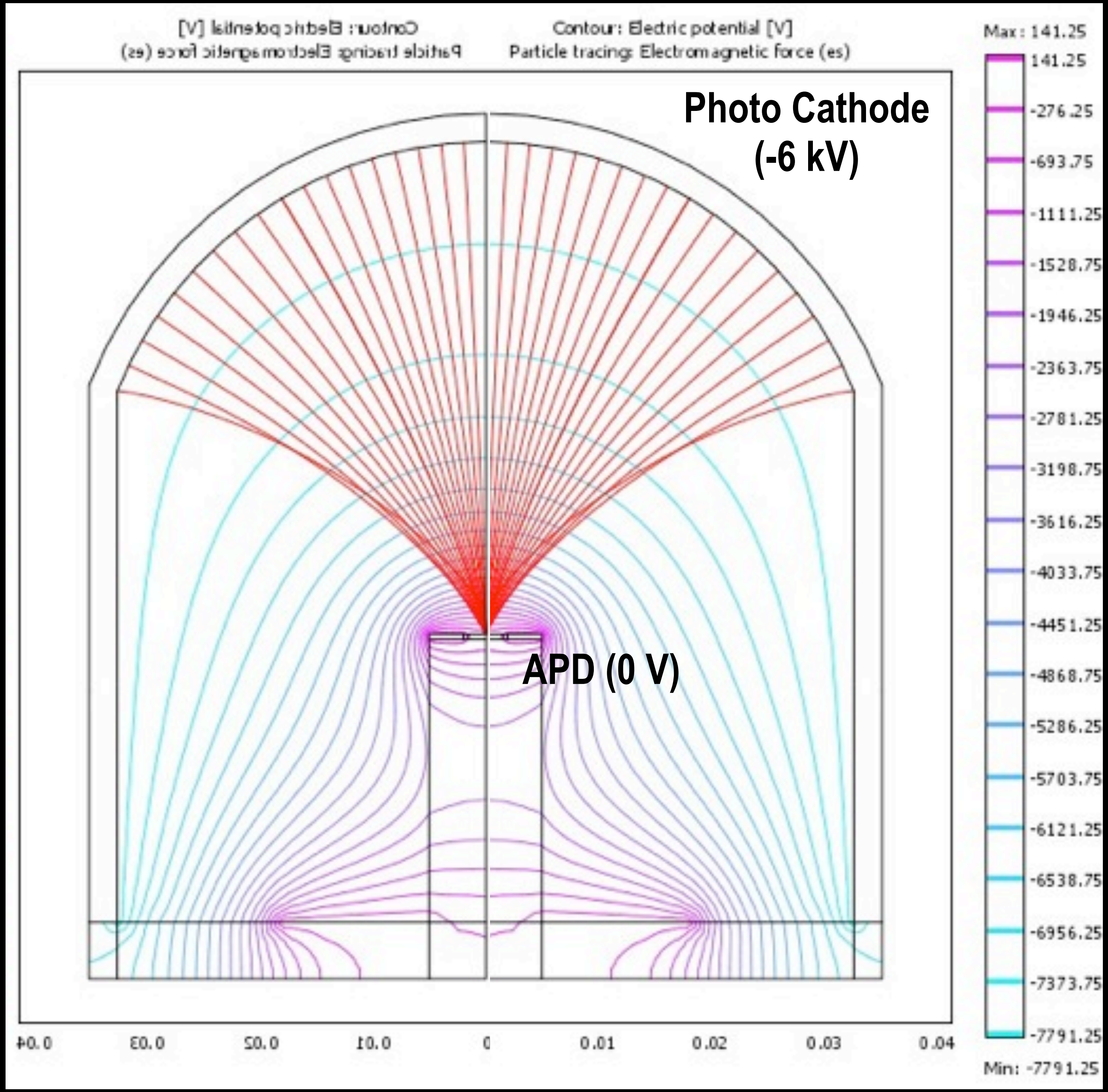
Princeton Prototype Plant for Industrial Scale Production

News: NSF funding (NSF PHY-0811186)

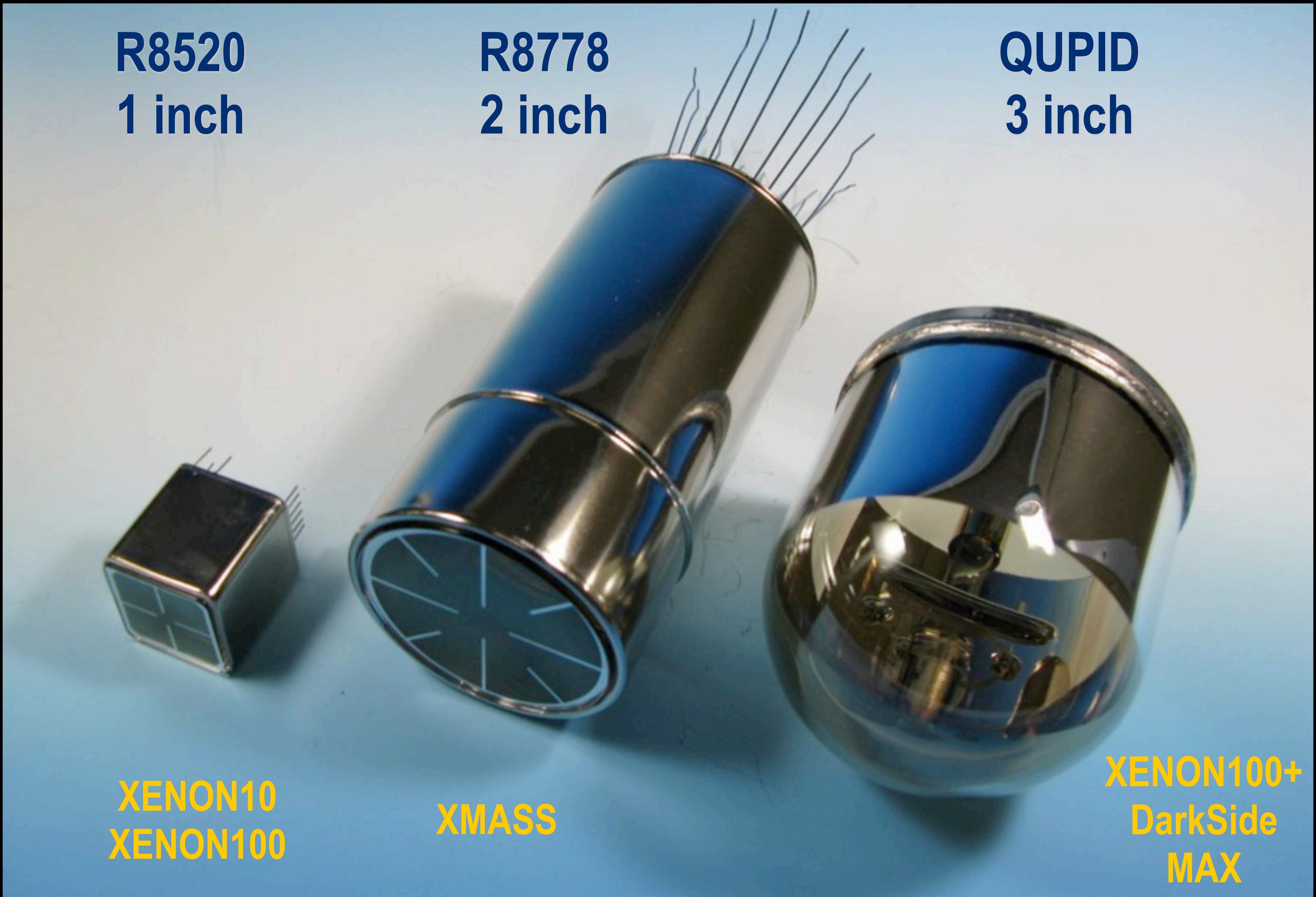
Achieved 1.5 kg/day (depletion >25), goal ~few kg/day in 2010

3” Quartz Photon Intensifying Detector (QUPID)

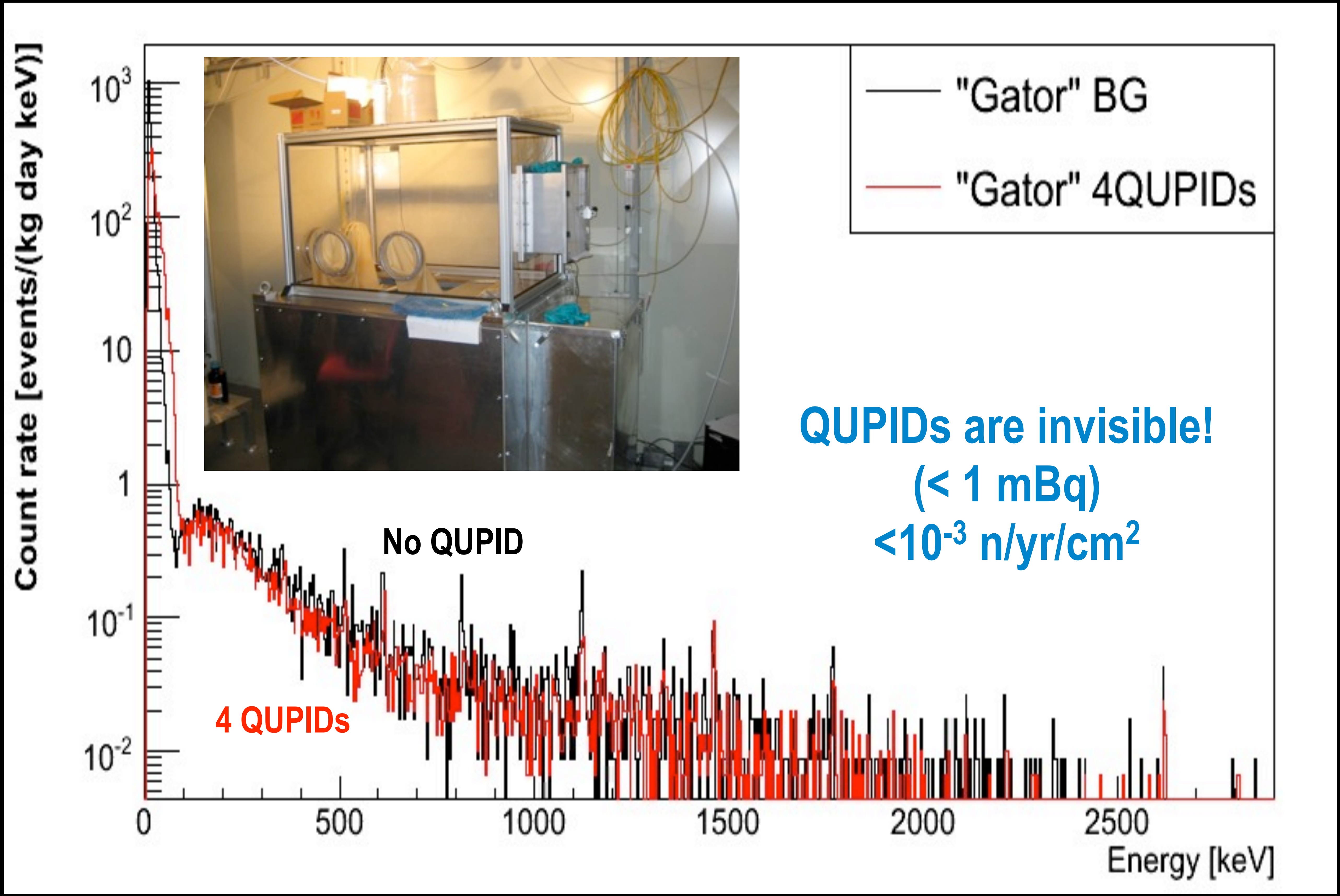




Low Radioactivity Photosensors for Dark Matter Searches



QUPID Radioactivity

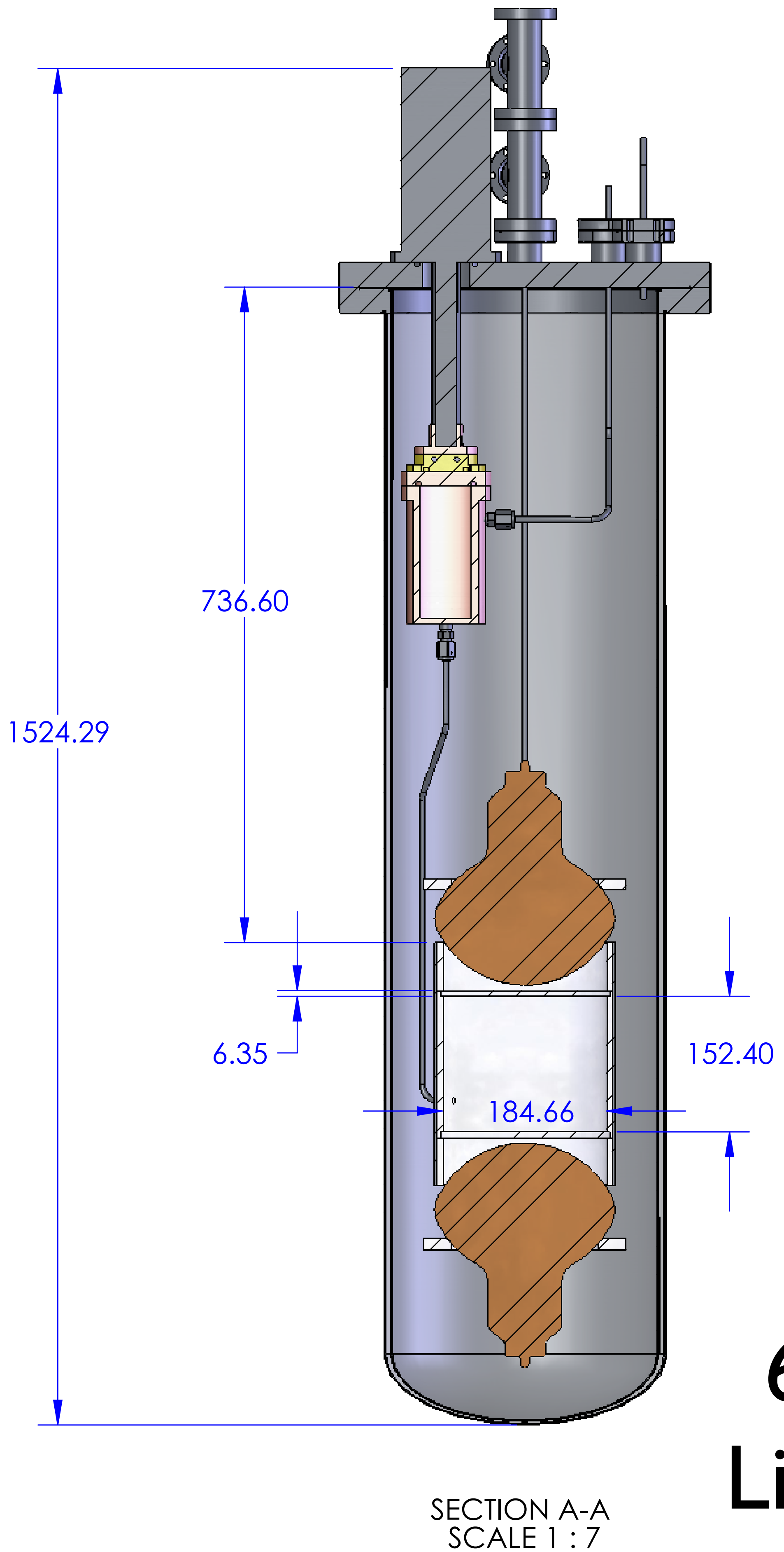


Neutron Veto

- Typical efficiency of xenon-based vetos ~60%
- Efficiency of 9-ton WARP liquid argon veto ~98%
- Efforts relying on neutron capture on Gd in water limited to 95% due to long range of γ-rays from capture

Neutron Veto

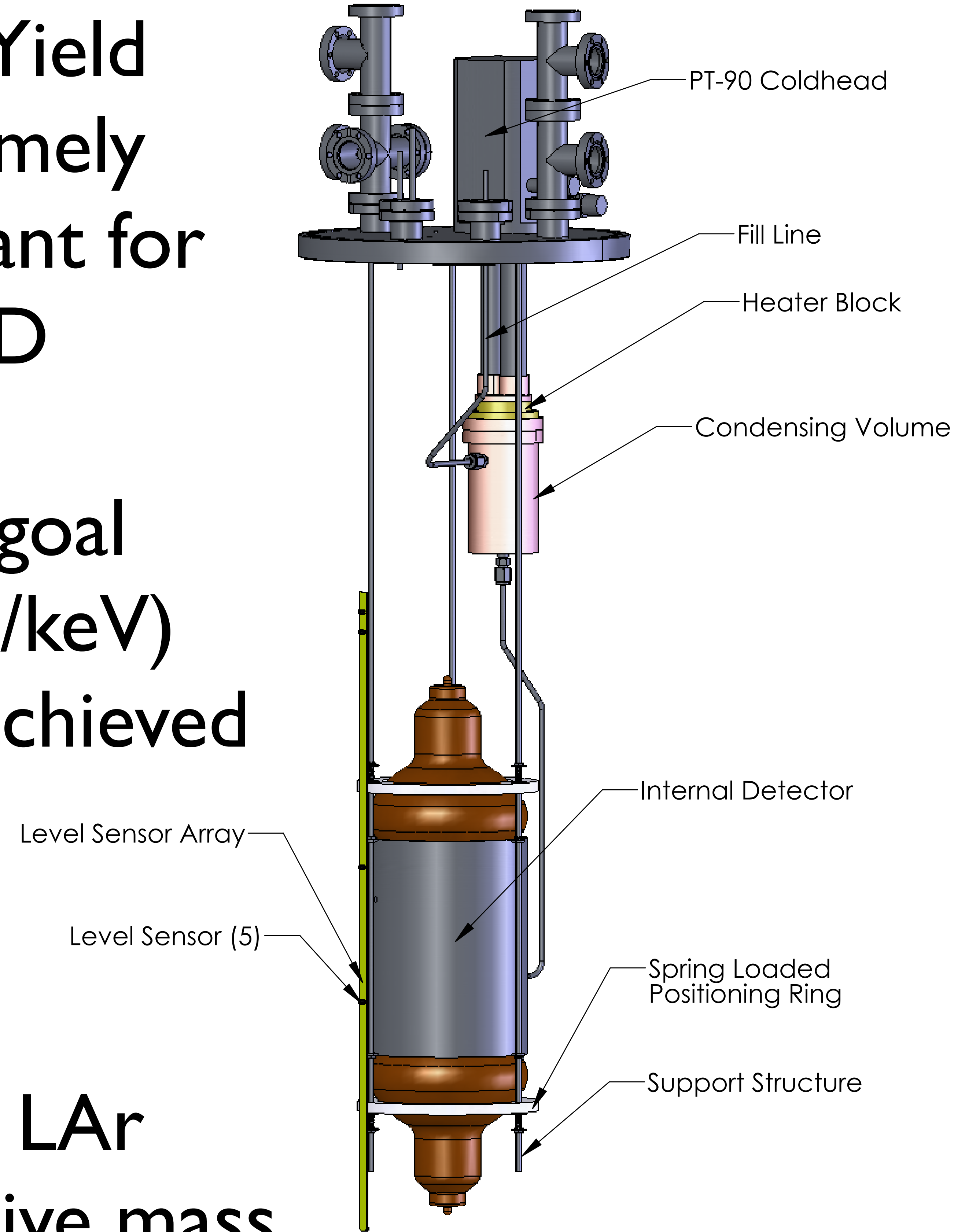
- Our approach (F. Calaprice): abandon (n,γ) capture agents, rely on (n,α) on ^{10}B
- Alpha particle extremely low range
- Alpha particle can be observed using borated liquid scintillator ... remember BOREX?
- 99.8% efficiency for radiogenic neutrons



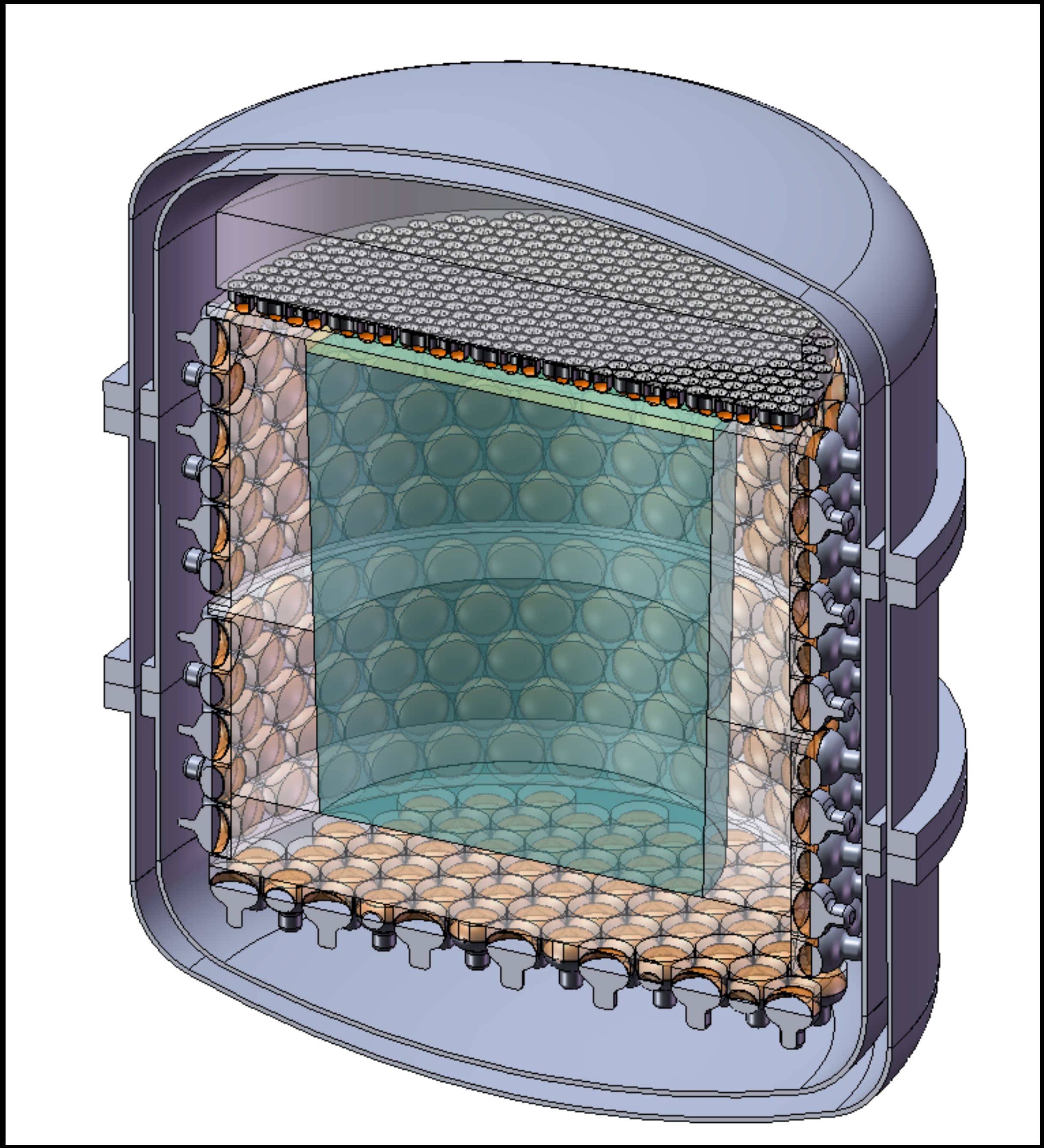
Light Yield extremely important for PSD

Our goal (>5 pe/keV) already achieved

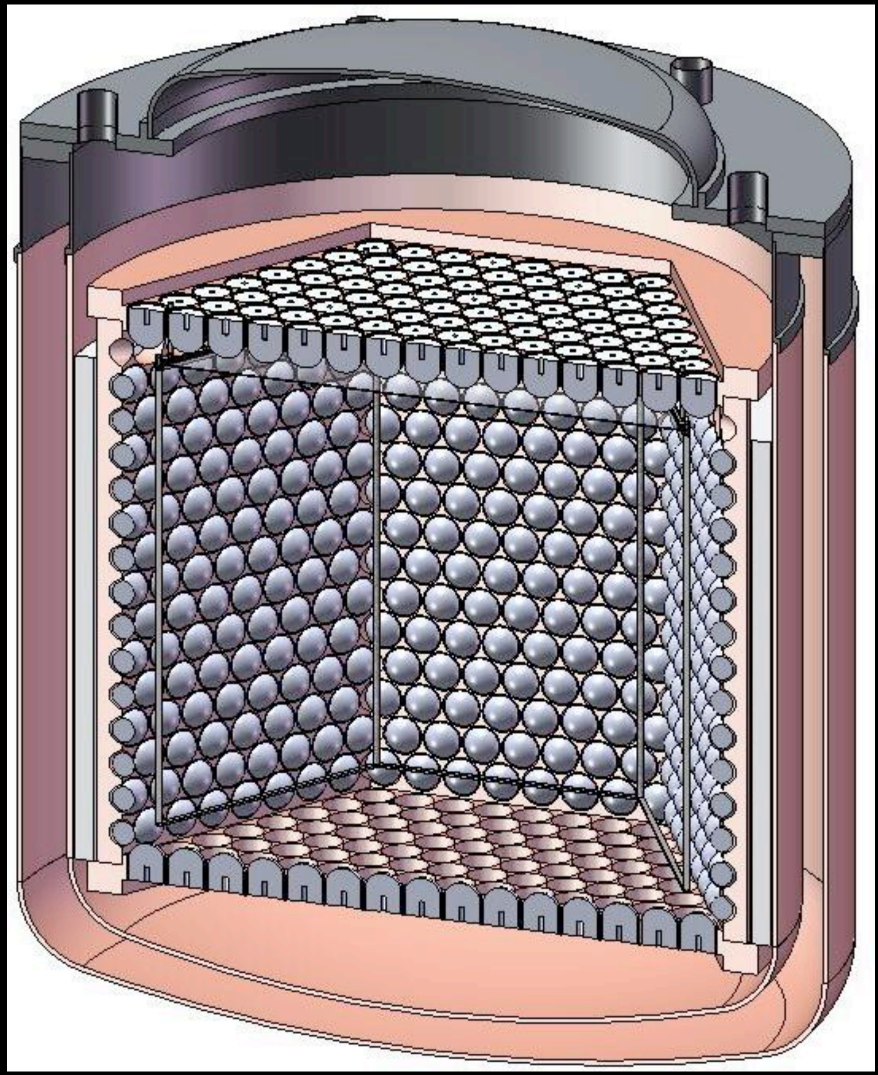
64 kg LAr
6.7 kg active mass
Light Yield: 5 pe/keV



MAX Concept

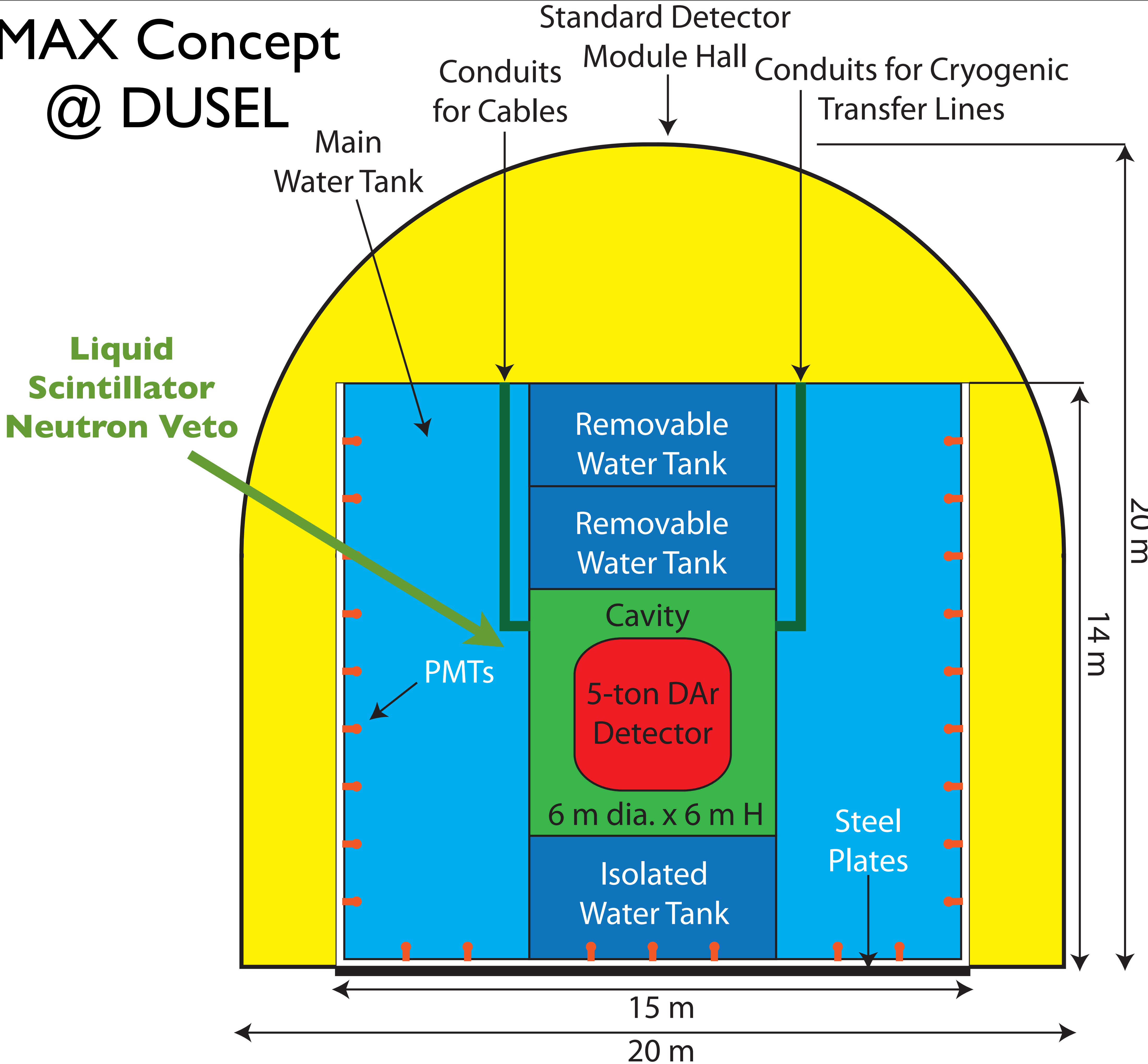


5 ton DAr TPC

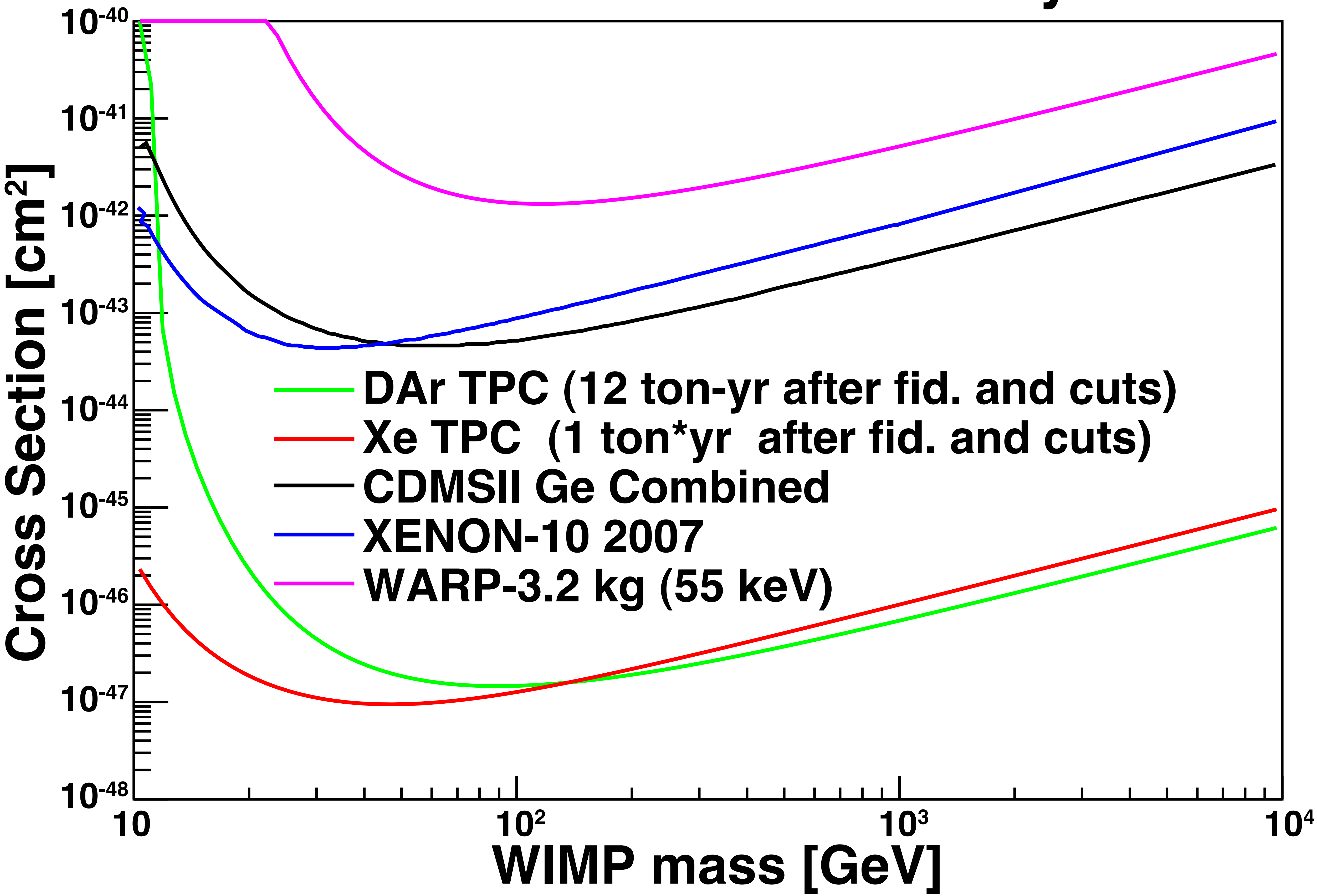


2.5 ton Xe TPC

MAX Concept @ DUSEL



Cross Section Sensitivity



MAX - Multi-ton Argon & Xenon

UMass Amherst
Arizona State University
Augustana College
Black Hills State University
Coimbra University
Columbia University
Fermilab
University of Houston
INAF
LNGS
MIT

University of Münster
University of Notre Dame
Princeton University
Rice University
Shanghai Jiao Tong University
Temple University
UCLA
University of Virginia
Waseda University
University of Zürich

Arizona State University, USA Prof. Ricardo Alarcon, Septimiu Balascuta

Augustana College, USA Prof. Drew Alton

Black Hills State University, USA Prof. Dan Durben, Prof. Kara Keeter, Prof. Michael Zehfus

Columbia University, USA Prof. Elena Aprile, Bin Choi, Dr. Karl-Ludwig Giboni, Dr. Tom Haruyama, Dr. Rafael Lang, Kyungeun Elizabeth Lim, Dr. Antonio Jesus Melgarejo, Guillaume Plante, Dr. Gordon Tajiri

Fermi National Accelerator Laboratory, USA Dr. Steve Brice, Dr. Aaron Chou, Pierre Gratia, Dr. Jeter Hall, Dr. Stephen Pordes, Dr. Andrew Sonnenschein

Instituto Nazionale di Astrofisica (INAF) Gianmarco Bruno, Dr. Walter Fulgione

Laboratori Nazionali del Gran Sasso (LNGS), Italy Dr. Francesco Arneodo, Serena Fattori

Massachusetts Institute of Technology, USA Prof. Jocelyn Monroe

Princeton University, USA Jason Brodsky, Huajie Cao, Alvaro Chavarria, Ernst de Haas, Prof. Cristiano Galbiati, Augusto Goretti, Andrea Ianni, Tristen Hohman, Ben Loer, Prof. Peter Meyers, Pablo Mosteiro, David Montanari, Allan Nelson, Eng. Robert Parsells, Richard Saldanha, Eng. William Sands, Jingke Xu

Rice University, USA Prof. Uwe Oberlack, Yuan Mei, Dr. Petr Shagin

Shanghai Jiao Tong University, PRC Prof. Xiangdong Ji, Prof. Kaixuan Ni, Yuehuan Wei, Xiang Xiao.

Temple University, USA Prof. Susan Jansen-Varnum, Christy Martin, Prof. Jeff Martoff, John Tatarowicz

University of California at Los Angeles, USA Daniel Aharoni, Prof. Katsushi Arisaka, Ethan Brown, Prof. David Cline, Yixiong Meng, Dr. Emilija Pantic, Prof. Peter F. Smith, Artin Teymourian, Chi Wai Lam, Dr. Hanguo Wang

University of Coimbra, Portugal Dr. Joao Cardoso, Lúis Carlos Costa Coelho, Prof. Joaquim Marques Ferreira dos Santos, Prof. José António Matias Lopes, Dr. Sonja Orrigo, Antonio Ribeiro

University of Houston, USA Prof. Ed Hungerford and Prof. Lawrence Pinsky

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University of Muenster, Germany Dr. Marcus Beck, Dr. Volker Hannen, Karen Hugenberg, Dr. Hans-Werner Ortjoahnn, Prof. Christian Weinheimer

University of Notre Dame, USA Prof. Philippe Collon, Daniel Robertson, Christopher Schmitt

University of Virginia, USA Prof. Kevin Lehmann

University of Zürich, Switzerland Ali Askin, Prof. Laura Baudis, Dr. Alfredo Ferella, Marijke Haffke, Alexander Kish, Dr. Roberto Santorelli, Dr. Eirini Tziaferi

Waseda University, Japan Prof. Tadayoshi Doke, Prof. Nobuyuki Hasebe, Mitsuteru Mimura, Dr. Mitsuhiro Miyajima, Dr. Shinichi Sasaki, Dr. Satoshi Suzuki, Prof. Shoji Torii

DarkSide-50

- $1.7M estimated equipment costs
- Depleted Argon independently funded (NSF PHY-0811186)
- Proposal submitted to NSF Oct 2009 (Princeton, Temple, Houston, UCLA, UMass, Augustana)
  - Requests 100% of equipment costs
- Proposal to DOE in preparation (FNAL, Princeton, UCLA)

MAX

- Funded NSF S4 effort for Engineering and R&D
    - NSF University groups already staffed
- DOE Field Work Proposal will request support for Engineering and R&D at FNAL

Request for Personnel

- DarkSide-50
  - 1 Application Physicist
  - 0.5 FTE Mechanical
  - 0.5 FTE Electrical
- MAX
  - NSF Groups already staffed and at work!
  - Build up to 2.5 FTE from 2010 to 2012

Synergies at FNAL

- LAr Neutrino Program (LBNE, MicroBoone, ArgoNeut)
  - Purification, DAQ, Electronics, Material Qualification, Wavelength Shifters, Optical Measurements and Simulations, Data Storage, Analysis, Electrostatics Design, HV Feedthroughs, Power and readout of QUPIDs and PMTs
- CDMS
  - Neutron Veto, Low Background Materials and Measurement, Cryogenics
- COUPP
  - Neutron Veto, Quartz Vessel

Fermilab Responsibilities

- DarkSide-50:
  - Cryogenic Simulations
  - DAQ and Electronics (w Houston)
  - Purification (w Temple)
  - Shielding and Muon Veto
- MAX:
  - See WBS of MAX S4 proposal

Facilities at Fermilab

- Possible operation of first prototype at moderate depth in NuMI tunnel (300 m.w.e)
- Material testing program at PAB
- Engineering in DAQ, Electronics, Mechanical, Cryogenics

PAC Questions

- In the context of the PASAG recommendations, is the science in the proposal interesting and/or compelling today?
  - Absolutely
- How does the proposed experiment relate to Fermilab's mission?
  - It does indeed. Understanding Universe and Dark Matter at the core of FNAL Mission. See Talk from Dan Bauer.
- Could/should the proposed experiment be part of a coherent Fermilab particle astrophysics program?
  - Yes. Tremendous synergies with larger program and interest of Fermilab scientists.

PAC Questions

- What is the competition for reaching the physics goals of the proposed experiment? Does the proposed experiment have particular advantages or disadvantages relative to the competition?
  - XENON, LUX, CDMS, WARP, DEAP/CLEAN, COUPP (list may be not complete).
  - Advantages of our approach: combined scalability and high discrimination power, unique combination of three innovative techniques.

PAC Questions

- What is unique about Fermilab and its proposed role in the experiment? Is the proposed Fermilab role appropriate and significant?
    - Unique particle astrophysics center, strongest dark matter effort among national labs.
    - Fermilab is the "dark matter lab" among national labs. See talk of Dan Bauer.
    - Unique liquid argon program for neutrinos, significant synergies on multiple experimental techniques
- What is needed to make such an experiment successful? Is Fermilab necessary for the experiment to succeed?
    - Timely Support. This program needs the participation of a national lab.

Request to PAC
P-1000

- Endorsement of FNAL participation in DarkSide-50

Request to PAC P-1001

- Endorsement of FNAL participation in MAX

Built upon Support from:

NSF PHY-0919363
"MAX - Multi-ton Argon and Xenon TPCs"

NSF PHY-0811186
"DUSEL R&D: Depleted Argon from Underground Sources"

NSF PHY-0704220
"Study of Argon for WIMP Dark Matter Detectors and Earth Sciences"

NSF PHY-0603376
"WARP: WIMP Dark Matter search with Liquid Argon"

Program Goal

- Bring together three innovative techniques
  1. Depleted Argon from underground sources
  2. 3" QUPID photosensors
  3. High efficiency borated liquid scintillator neutron veto (>99%)
- Goal of zero background with very large exposures to dark matter
  - Many tons fiducial target
  - Many years of background-free exposure

The End

Like the jelly beans in this jar, the Universe is mostly dark: 96 percent consists of dark energy (about 70%) and dark matter (about 26%). Only about four percent (the same proportion as the lightly colored jelly beans) of the Universe - including the stars, planets and us - is made of familiar atomic matter.

The End